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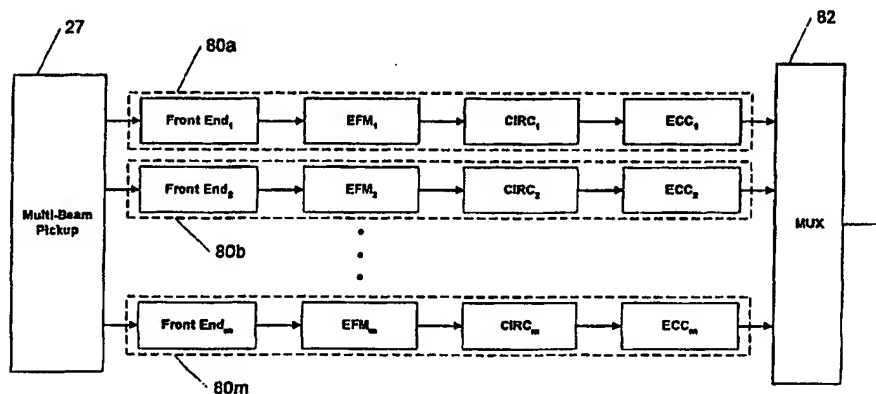
(57) Abstract

Methods and apparatus are provided for synchronously reading data from multiple tracks of an optical disk using multiple illumination beams. Circuitry is provided for use with a photodetector array to read and buffer data in parallel from the multiple adjacent tracks, while asynchronously providing processed data to a host processor. Circuitry is further provided for concurrently processing the signals read from the multiple data tracks to recover the data stored in the tracks.

METHODS AND APPARATUS FOR CONCURRENTLY
PROCESSING DATA FROM MULTIPLE TRACKS
OF AN OPTICAL STORAGE MEDIUM

Field of the Invention

5   This invention relates to methods and
apparatus for retrieving information from an optical
disk at high data rates by simultaneously and
synchronously reading multiple adjacent tracks.

Background of the Invention

10   Due to their high storage density, long data
retention life, and relatively low cost, optical disks
are becoming increasingly popular as a means to
distribute information. Large format disks have been
developed for storing full length motion pictures. The
15   compact disk (CD) format was developed and marketed for
the distribution of musical recordings and has replaced
vinyl records. High-capacity, read-only data storage
media, such as CD-ROM and DVD, have become prevalent in
the personal computer field, to the point that the DVD
20   format may soon replace videotape as the distribution
medium for video information.

          An optical disk is made of a transparent disk
or substrate in which data, in the form of a serial
bit-stream, are encoded as a series of pits in a

reflective surface within the disk. The pits are arranged along a spiral or circular track. Data are read from the optical disk by focusing a low power laser beam onto a track on the disk and detecting the

5 light reflected from the surface of the disk. By rotating the optical disk, the light reflected from the surface of the disk is modulated by the pattern of the pits rotating into and out of the laser's field of illumination. Optical and imaging systems detect the

10 modulated, reflected, laser light and produce an electrical signal which may be decoded to recover the digital data stored on the optical disk. The recovered digital data, which may include error correcting codes and additional subcoded information, are further

15 processed to recover the stored data which may then be converted to audio signals, or used as executable programs and data depending on the type of optical disk being read.

To be able to retrieve data from anywhere on

20 an optical disk, the optical systems include a pickup assembly which may be positioned to read data from any disk track. Servo mechanisms are provided for focusing the optical system and for keeping the pickup assembly positioned over the track, despite disk warpage or

25 eccentricity.

Because in most previously known systems the data are retrieved from the disk serially, i.e. one bit at a time, the maximum data transfer rate for an optical disk reader is determined by the rate at which

30 the pits pass by the pickup assembly. The linear density of the bits and the track pitch are fixed by the specification of the particular optical disk format. For example, CD disks employ a track pitch of

1.6 μm, while DVD employs a track pitch only about one-half as wide.

Previously known methods of increasing the data transfer rate of optical disk readers have focused
5 on increasing the rate at which the pits pass by the pickup assembly by increasing the rotational speed of the disk itself. Currently, drives with rotational speeds of up to 16× standard speed are commercially available, and even faster speeds have been achieved by
10 moving to constant angular velocity designs. However higher disk rotational speeds place increasing demands on the optical and mechanical subsystems within the optical disk player, create greater vibration, and may make such players more difficult and expensive to
15 design and manufacture.

Other previously known techniques for increasing average data transfer rates involve methods to intelligently anticipate future read requests by a host processor. It has been observed that data access
20 by computers frequently exhibit "locality of reference," which means that a future data access will be local, in either space or time, to a previous data access. Thus a CD-ROM drive or controller can "read ahead" and buffer the data that the host processor is
25 likely to request next. When the host processor next requests data from the optical disk drive, the drive first checks if the requested data have already been read and buffered. If the data have already been buffered, the drive simply sends the buffered data to
30 the host, avoiding the delays associated with repositioning the pickup assembly and reading data from the optical disk itself. While such caching techniques may speed up average data access times, the maximum data transfer rate is still limited by the rotational

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velocity of the optical disk within the optical disk reader.

Commonly assigned U.S. patent 5,627,805 describes a system to increase disk reading speeds by
5 reading multiple tracks simultaneously. The data is read using a wide area reading beam, which is focussed onto a plurality of tracks on the disk. A detector comprising a matrix of photo-detector elements provides an image of the wide area, from which track signal data
10 for each of a plurality of tracks is extracted by a virtual tracking system. Alternatively, the track data signals may be provided by an optical pickup which uses multiple beams to simultaneously read multiple tracks of an optical disk. The track data signals are then
15 sampled, to produce a plurality of digital data streams, which are multiplexed into a single data stream before demodulation, decoding, and error correction.

Since the multiplexed data stream contains
20 data from multiple tracks, which may be read from a disk that is spinning at multiple times the standard speed, the rate at which data in the multiplexed stream must be processed may be very high. For example, in a multi-beam CD-ROM reader that reads seven tracks
25 simultaneously and spins the disk at 8× the standard speed (giving the approximate equivalent of a 56× drive), the data rate in the multiplexed data stream will be approximately 240 million bits per second in the demodulation stage (17 million words per second at
30 14 bits per word). By the time the data reaches the error correction stage, the required data rate will have dropped to approximately 79 million bits per second (9.9 million bytes per second). As can be seen, the rate at which data in such a system must be

processed requires use of high performance devices to perform the functions at each of the stages in the processing chain.

The present application is directed to an
5   improvement in the system described in the above-incorporated patent, wherein the multiplexer is moved to a later position in the processing chain, so that the plurality of data streams from multiple tracks on the disk may be demodulated, decoded, and error
10 corrected before being multiplexed into a single data stream. Apparatus in accordance with the present invention may use a plurality of inexpensive, relatively low performance devices to perform the steps of demodulation, decoding, and error correction, while
15 delivering throughput similar to that achieved by a high performance device performing these operations on a single multiplexed stream of data. Using the techniques of the present invention, it may be possible to construct a high performance system for processing
20 the multiple data streams read from an optical disk, and which has a higher throughput than other similar systems, using standard low cost components.

It would therefore be desirable to provide apparatus and methods which permit simultaneous
25 processing of data from multiple tracks in an optical disk reader.

It would also be desirable to provide demodulation, decoding, and error correction circuitry having higher throughput and at lower cost than
30 previously known circuitry for processing the data from multiple tracks in an optical disk reader.

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Summary of the Invention

In view of the foregoing, it is an object of
the present invention to provide apparatus and methods
for simultaneous processing of data from multiple
5   tracks in an optical disk reader.

It is a further object of this invention to
provide demodulation, decoding, and error correction
circuitry having higher throughput and faster time to
market than previously known circuitry for processing
10   the data from multiple tracks in an optical disk
reader.

These and other objectives of the invention
are accomplished by placing the multiplexer in a
position late in the processing stream, so that the
15   data from the multiple tracks remain separate through
the processing stages of demodulation, decoding, and
error correction. Implementation of this scheme
requires providing multiple demodulation, decoding, and
error correction units.

20   Alternatively, the multiplexer may be placed
in the processing chain between the demodulation stage
and the decoding stage, so that demodulation is
performed in parallel on the multiple data streams, but
decoding and error correction are performed on a
25   single, multiplexed data stream. The multiplexer could
also be placed in the processing stream between the
decoding stage and the error correction stage, so that
demodulation and decoding are performed in parallel on
the multiple data streams, and error correction is
30   performed on a single, multiplexed data stream.

Further features of the invention, its nature
and various advantages will be more apparent from the
accompanying drawings and the following detailed
description of the preferred embodiments.

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Brief Description of the Drawings

FIG. 1 is an illustrative block diagram of a previously known single beam optical disk reader;

FIG. 2 is an illustrative block diagram of a
5　multi-beam optical disk reader;

FIG. 3 is a block diagram of a multi-beam optical disk reader built in accordance with the principles of the present invention;

FIG. 4 is a block diagram of the front end
10　circuitry for extracting data from the signals output by the pickup assembly of FIG. 3;

FIGS. 5A, B, and C are block diagrams of the demodulator circuitry, decoder circuitry, and error correction circuitry, respectively, of the optical disk
15　reader of FIG. 3;

FIGS. 6 and 7 are block diagrams of alternative embodiments of multi-beam optical disk readers built in accordance with the principles of the present invention; and

20　FIG. 8 is a block diagram of an alternate arrangement for the processing chain of an optical disk reader built in accordance with the principles of the present invention.

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Detailed Description of the Invention

By way of overview, a brief description of the components and operation of a previously known optical disk reader 10 is provided with respect to FIG.

5   1. The detailed description of the design and operation of such previously known optical disk readers may be found, for example, in Compact Disk Technology, H. Nakajima and H. Ogawa, published by Ohmsha, Ltd., Japan (1992), translated by Aschmann, C., IOS Press,

10   Inc., Burke, Virginia, and The Compact Disk Handbook, Ken C. Pohlmann (2nd Ed. 1992), A-R Editions, Inc., Madison, Wisconsin, both of which are incorporated herein in their entirety by this reference. An overview of multi-beam optical disk reader 25 is given

15   with respect to FIG. 2.

It will of course be understood that the systems of FIGS. 1 and 2 are merely illustrative of the various types of optical disk apparatus in which the methods and apparatus of the present invention may be

20   employed. Applicants expect that the invention described herein may be advantageously employed in any multi-beam optical disk system, including DVD systems.

Overview Of A Prior Art Optical Disk System

Referring to FIG. 1, illustrative previously

25   known optical disk reader 10 comprises a spindle motor 11 that rotates optical disk 100 at high speed and pickup 12 including an illumination source and a photodetector for generating electrical signals representative of information-bearing pits formed in a

30   reflective surface within optical disk 100. The electrical signals from the photodetector of pickup 12 are then passed to front end circuitry 13 for extracting a digital data signal. Under the control of

controller 24, the data signal is further processed by
eight-to-fourteen (EFM) demodulation circuitry 17,
Cross Interleaved Reed-Solomon Code (CIRC) decoding
circuitry 18, error correction code (ECC) circuitry 19,
5   and subcode circuitry 16. Controller 24 also controls
focus and tracking circuitry 14, as well as buffer 20
and interface 22.

        For a digital audio system, the data signals
may be processed into suitable analog signals (using
10 circuitry not shown) connected to audio means 21.
Similarly, if the optical disk contains video images,
the data signals may be processed for display on a TV
or monitor. In computer applications the data signals
are typically transferred from buffer 20 to host
15 processor 23 via interface 22.

        Spindle motor 11 spins optical disk 100 at a
speed that depends upon the radial location of pickup
assembly 12 (for example, for a 1× CD-ROM spindle
speed, approximately 200-500 RPM), to maintain a
20 constant linear velocity of an optical disk track
relative to pickup assembly 12. For a CD-ROM format,
this linear velocity is generally 1.4 m/s, while for
the DVD format it approaches 4 m/s. Pickup assembly 12
typically includes a laser diode that illuminates only
25 a single data track on optical disk 100 and an optical
sensor onto which an image reflected from the optical
disk is projected. The intensity, or other property,
of the light beam reflected from the surface of optical
disk 100 is modulated by inhomogeneities in the
30 reflective surface of the optical disk (i.e., bumps or
pits, referred to hereinafter as "data spots") arranged
in spiral or circular tracks on optical disk 100.

        Pickup assembly 12 includes circuitry to
generate an electronic signal representative of the

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modulation in the illumination impinging upon its
optical sensor due to the presence of the data spots.
To ensure that the laser illumination remains focused
on the reflective surface of optical disk 100, pickup
5   assembly 12 also provides signals to focus and tracking
subsystem 14.

The data spots are recorded on optical disk
100 using a modulation code that permits a data clock
to be recovered from the data as it is read off of the
10   optical disk. Clock circuitry 15 includes phase-
locked-loop (PLL) circuitry for recovering the data
clock from, and maintaining the data clock in synchrony
with, the modulated electronic signal from pickup
assembly 12. In addition to being used for extracting
15   the data from the modulated signal, the data clock is
representative of the linear velocity of the data track
relative to pickup assembly 12 and may be used as a
feedback signal to control the speed of spindle motor
11 to maintain a constant linear velocity.

20   Front end circuitry 13 uses the data clock
from PLL 15 to recover a serial stream of bits from the
electronic signal. Front end circuitry 13 contains
additional circuitry to identify synchronization codes
in the bit stream so that the serial bit stream may be
25   correctly assembled into multi-bit data words which are
transferred to demodulation circuitry 17. Demodulation
circuitry 17 may be programmed for eight-to-fourteen
demodulation, eight-to-fifteen demodulation (as in the
SD systems), eight-to sixteen demodulation (EFM Plus),
30   or may use another suitable demodulation scheme. The
demodulated data words, or symbols, are then assembled
into blocks and decoded by CIRC decoder 18 using a form
of Cross Interleaved Reed-Solomon code, for example,
CIRC for CD-formats and PI PO structure for DVD.

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Demodulated data words are also provided to subcode
processor 16 which extracts data, such as block
numbers, or song titles, that may be recorded in the
subcode channels embedded in each block of data words.

5   For video and audio optical disk players, the
data from CIRC decoder 18 represents, in digital form,
the video or audio signal that was originally recorded
and stored on the disk. These signals may then be
converted to analog signals and the original recorded

10   signal reproduced using conventional audio or video
devices 21. Errors in the recovered audio or video
signals are handled by interpolation and filtering
circuitry (not shown) to calculate a value to use in
place of the erroneous data. Because of the

15   interpolation process, isolated errors in an audio or
video signal are unlikely to be noticed when listening
to the audio or viewing the video signals.

          However, since a single bit error in data
representing a computer program may render the program

20   inoperable or the data unusable, optical disks used for
the storage and distribution of data and programs must
have very low data error rates. To reduce the data
error rates to acceptably low levels, error correction
codes (ECC) are added to the data when it is recorded

25   to the disk. ECC circuitry 19 uses error correcting
codes to detect and possibly correct errors in the
data. Finally, the data are buffered in memory buffer
20 for transfer to host processor 23 via interface
circuitry 22. Controller 24 coordinates operation of

30   each of the optical disk reader subsystems and to
control the operation of the optical disk reader as a
whole.

          Referring now to FIG. 2, an optical disk
reader similar to that described in U.S. Patent Number

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5,627,508 is described. Apparatus 25 provides a high
data transfer rate by reading multiple tracks of data
from an optical disk simultaneously. Much of the
circuitry of FIG. 2 may be common to or readily adapted
5   from the circuitry of the system of FIG. 1.
Accordingly, the following description focuses on the
differences between previously known single beam
optical disk reader 10 of FIG. 1, and multi-beam .
optical disk reader 25.

10   In particular, apparatus 25 includes a multi-
beam, multi-detector pickup assembly 27 that
simultaneously illuminates and reads multiple adjacent
data tracks of disk 100; phase-lock loop circuitry that
permits a clock 29 associated with a reference track to
15   be used for synchronizing the recovery of data from
neighboring tracks; and a parallel write/asynchronous
read architecture that enables blocks of data to be
read from the optical disk, processed and written to a
buffer in parallel while being asynchronously retrieved
20   from the buffer by a host computer.

          Multi-beam optical disk reader 25 of FIG. 2
includes pickup assembly 27 including a source of laser
illumination, a diffraction grating for splitting the
laser illumination into three or more illumination
25   beams and a corresponding number of photodetectors onto
which multiple illumination beams, reflected from the
optical disk, are focused by an optical system. Each
of the multiple photodetectors in pickup assembly 27
generates an electrical signal representing data read
30   from a corresponding data track on optical disk 100,
and provides that electrical signal to front end
circuitry 30.

          Front end circuitry 30 of FIG. 2 performs a
function similar to that of front end circuitry 13 of

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FIG. 1, except that multiple bit streams are processed
concurrently, so additional circuitry is provided for
buffering and synchronizing data transfers to
subsequent processing circuitry. Front end circuitry

5   30 also includes a multiplexer for routing multiple
data streams to demodulation circuitry 32 in the form
of a single multiplexed data stream.

Demodulation circuitry 32, subcode circuitry
31, decoder circuitry 34, and error correction

10   circuitry 36 of optical disk reader 25 are all similar
in operation to their counterparts in optical disk
reader 10 of FIG. 1. They differ principally in that
they may be required to handle a much greater data
throughput than similar circuitry used in single-beam

15   optical disk reader 10.

Buffer memory 33 is provided to buffer the
data read from the multiple data tracks, and to
decouple the process of reading data from optical disk
100 from the process of transferring the data to host

20   processor 37. Buffer 33 therefor is large enough to
hold about as many data blocks from multiple data
tracks of optical disk 100 as can be read in one
revolution of optical disk 100. Controller 38 maps
data from the multiple data tracks to memory 33 so that

25   individual data blocks will be correctly assembled
without overwriting one another. As will be
appreciated by those of skill in the art of buffer
design, this mapping may be either dynamic or static.

Description of the Present Invention

30   Referring to FIG. 3, multi-beam optical disk
reader 40, constructed in accordance with the
principles of the present invention is described.
Multi-beam optical disk reader 40 is very similar to

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multi-beam optical disk reader 25, of FIG. 2, except
that multiple data streams are processed concurrently
through the entire processing chain, rather than just
the front end. Instead of using a multiplexer in front
5   end circuitry 42 to combine the multiple data streams
into a single multiplexed data stream, multi-beam
optical disk reader 40 places multiplexer 52 at the end
of the processing chain, after the data are read,
demodulated, decoded, and error corrected.

10   Front end circuitry 42 recovers multiple
streams of bits from the electronic signals
corresponding to the multiple tracks read by multi-beam
optical pickup 27, by recovering the clock for one
track, and adjusting that clock signal to account for
15   differences in the linear velocities of the tracks.
Alternatively, front end circuitry 42 may use a
separate phase-locked loop (PLL) for each track to
regenerate a clock signal for each of the tracks being
read. Front end circuitry 42 also assembles the
20   streams of bits into multi-bit data words which are
transferred to demodulation circuitry 44 as multiple
streams of data words.

            Demodulation circuitry 44 demodulates each of
the streams of data words into demodulated data words,
25   or symbols. These symbols are assembled into frames,
each containing multiple symbols, which are made
available to decoder circuitry 46 as multiple streams
of frames. Demodulation circuitry 44 may be programmed
for eight-to-fourteen demodulation, eight-to-fifteen
30   demodulation (as in the SD systems), eight-to sixteen
demodulation (EFM Plus), or may use another suitable
demodulation scheme. Demodulated data words are also
provided in multiple streams to subcode processor 43
which extracts data, such as frame numbers, or song

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titles, that may be recorded in the subcode channels embedded in each frame of data words.

Decoder circuitry 46 uses a form of Cross Interleaved Reed-Solomon Code, such as CIRC for CD-
5 formats and PI PO structure for DVD, to decode the frames of data received in each of the data streams. The decoded frames are then assembled into sectors, which contain the data from multiple frames, and are made available to error correction circuitry 48 as
10 multiple streams of sectors. Each sector contains a sector type identifier, used for determining which type of error correction or other processing to perform on the sector. Sectors also contain synchronization codes, data, and may contain error correction codes.
15   If the sector type identifier indicates that a sector contains error correction codes, error correction circuitry (ECC) 48 uses the error correction codes to detect and possibly correct errors in the data. The corrected data from each of the data streams
20 is then made available to buffer memory 50 through multiplexer (MUX) 52. Buffer memory 50 uses MUX 52 to select one of the data streams, and transfers one sector of corrected data from ECC circuitry 48 to memory. Buffer memory 50 permits stored data to be
25 transferred to host processor 23 via interface circuitry 22.

Controller 54 coordinates operation of each of the optical disk reader subsystems and controls the operation of the optical disk reader as a whole.
30   FIG. 4 shows a detailed view of front end circuitry 42, constructed using a separate PLL for each track. Multi-beam pickup assembly 27 outputs track data signals, $T_1...T_m$, corresponding to m tracks being

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read. Since an accurate data clock is needed to
extract data from a track data signal, and the signals
from each track will differ in frequency and phase, the
track data signals $T_1...T_m$ are provided to separate

5   phase-locked loops (PLLs) 56 which are used to recover
a clock signal for each track. These clock signals are
used by data samplers 57 to recover digital data from
the tracks. The serial bit streams are assembled into
parallel data words and are then sent to first-

10 in/first-out buffers (FIFOs).

For an 8× multi-beam CD-ROM reader, each
stream in front-end circuitry 42 will produce
approximately 2.5 million 14-bit data words per second,
which can easily be handled by inexpensive commercially

15 available circuitry. By contrast, if the data from an
8× speed, seven-beam system were combined into a single
data stream at the front end stage of processing, the
data rate would be approximately 17.5 million 14 bit
words per second.

20   It will, of course, be understood that
methods and apparatus which permit a common clock to be
used to recover clocks for all of the track data
signals, alternatively could be used in the front end
circuitry of a multi-beam optical disk reader built in

25 accordance with the principles of the present
invention.

Referring now to FIGS. 5A-C, demodulator
circuitry 44, decoder circuitry 46, and error
correction circuitry 48 are shown. Demodulator

30 circuitry 44, shown in FIG. 5A, comprises m single-
stream demodulator units 60, each of which handles the
data words sent to it through one FIFO 58 of front end
circuitry 42. Each of demodulator units 60 demodulates

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data words from one track into demodulated data words,
or symbols, and assembles the symbols into frames.
Additionally, demodulator units 60 may extract subcode
data from the data stream, and send the subcode data to
5   subcode processor 43.

For an 8× multi-beam CD-ROM reader, each
demodulator unit 60 assembles 58,800 frames per second,
each frame containing 32 bytes, for a total of
approximately 1.9 million bytes per second. If the
10   data from a seven beam, 8× system were combined into a
single stream at the demodulator stage, the combined
data stream would have a data rate of approximately
13.2 million bytes per second. Thus, applicant expects
that retaining multiple data streams will permit use of
15   a greater number of lower cost (slower) components.

FIG. 5B shows decoder circuitry 46, which
comprises one single-track Cross Interleaved Reed-
Solomon Code (CIRC) decoder unit 62 for each of the m
data tracks being processed. Data from demodulator
20   units 60 are sent into CIRC decoder units 62. Each of
CIRC decoder units 62 decodes data from a single track,
and assembles the data into sectors, which are sent to
error correction circuitry 48.

For an 8× multi-beam CD-ROM reader, each CIRC
25   decoder unit 62 assembles 600 sectors per second, each
sector containing 2352 bytes, for a total of
approximately 1.4 million bytes per second. If the
data from a seven beam, 8× system were combined into a
single stream at the decoder stage, the combined data
30   stream would have a data rate of approximately 9.9
million bytes per second.

FIG. 5C shows error correction circuitry 48,
which comprises one single-track error correction unit

64 for each of the **m** data tracks being processed. Data
from CIRC decoder units 62 are sent into the error
correction units 64. Each of the error correction
units 64 examines a sector-type identifier byte for
5   each sector sent by CIRC decoder units 62 to determine
which error correction technique (if any) to perform on
a sector. If error correction is required, error
correction unit 64 applies the error correction
technique indicated by the sector-type identifier byte,
10 and outputs the corrected sector data. If the sector
is of a type which does not require correction, error
correction unit 64 need only strip any synchronization
bytes, or other extraneous formatting from the sector
data.

15   For an 8× multi-beam CD-ROM reader, each
error correction unit 64 processes 600 sectors per
second, each sector containing up to 2336 bytes of
data, plus four bytes of header information, for a
total of approximately 1.4 million bytes per second. A
20 multiplexer combining data from a seven beam, 8× system
after the error correction stage would need to be able
to handle a throughput of approximately 9.8 million
bytes per second.

           Referring now to FIG. 6, an alternate
25 embodiment of a multi-beam optical disk reader built in
accordance with the principles of the present invention
is shown. As will be understood from the above
discussion, the data rate of a single multiplexed data
stream becomes smaller in later stages of the
30 processing chain. It may therefore be practical to use
circuitry which processes the track data concurrently
for the early stages in the processing chain, such as
the front end processing and demodulation, where the

data rate is highest, while using circuitry which processes a single data stream for later stages, such as decoding and error correction. Accordingly, in optical disk reader 60, Multiplexer 62 has been placed
5 between demodulation circuitry 44 and decoder circuitry 34 in the processing chain. Multiplexer 62 combines the data from all of the single-track demodulation units of demodulation stage 44 into a single data stream. As shown in FIG. 6, multiplexer 62 sends the
10 combined stream of data to buffer memory 50, where it is stored until the frames are requested by host 23, or are no longer needed. Alternatively, if later stages are capable of handling the throughput required to process the combined data stream, buffer memory 50 can
15 be placed at the end of the processing chain, and the combined data stream from multiplexer 62 may be sent directly into decoder stage 34.

FIG. 7 shows another alternative embodiment, in which multiplexer 66 is located between decoder
20 circuitry 46 and error correction circuitry 36 in the processing chain. Multiplexer 66 combines the data streams from the single-track decoder units in decoder stage 46 into a single data stream, which is stored in buffer memory 50. If the error correction stage is
25 capable of handling the throughput required to process the combined data stream, buffer memory 50 may be placed at the end of the processing chain, after error correction stage 36.

FIG. 8 shows a yet further alternative
30 arrangement of the processing chain for a multi-beam optical disk reader constructed in accordance with the principles of the present invention. The processing chain shown in FIG. 8 is arranged according to which beam is being processed, rather than according to

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function. Thus, data from the first beam are sampled,
demodulated, decoded, and error corrected by data
stream processor 80a, while data from the second beam
are processed by data stream processor 80b, and so on.
5   Multiplexer (MUX) 82 multiplexes data from the data
streams into a single data stream. Embodiments in
which multiplexer 82 is located after the demodulator
(EFM) stage or the decoder (CIRC) stage may also be
arranged according to the beam being processed, rather
10 than by function.

Arranging the circuitry as shown in FIG. 8
permits standard, relatively inexpensive parts, which
were designed for use in single-beam optical disk
readers to be used to build a multi-beam optical disk
15 reader in accordance with the principles of the present
invention. Commercially available CD controllers
combine several of the processing stages of a single-
beam optical disk reader into a single integrated
circuit. The OTI-975, by Oak Technology of Sunnyvale,
20 California, for example, is capable of performing
decoding and error correction on a single data stream
for a 16× CD-ROM reader. Other commercial parts
manufactured by Philips Electronics N.V., and Sony
Semiconductor provide similar functions, and perform
25 clock recovery (using PLLs), data sampling, and
demodulation for use with a single-beam optical disk
reader. Data stream processors 80a-80m could be
assembled from such standard parts, and then combined
using MUX 82 to form the processing chain for a multi-
30 beam optical disk reader in accordance with the
arrangement of the circuitry shown in FIG. 8.

While preferred illustrative embodiments of
the present invention are described above, it will be
evident to one skilled in the art that various changes

and modifications may be made without departing from
the invention. It is intended in the appended claims
to cover all such changes and modifications which fall
within the true spirit and scope of the invention.

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What Is Claimed Is:

1. Apparatus for simultaneously reading multiple data tracks of an optical disk, the apparatus comprising:

a pickup assembly providing a plurality of data signals corresponding to data stored in a plurality of data tracks of an optical disk;

sampling circuitry for recovering a plurality of digital data streams from the plurality of data signals;

a multiplexer for combining the plurality of digital data streams into a single data stream; and

processing circuitry for extracting formatted data from the plurality of digital data streams, the processing circuitry comprising a concurrent portion, disposed before the multiplexer, wherein the plurality of digital data streams are processed simultaneously, and a serial portion, disposed after the multiplexer, wherein the single data stream is processed to produce the formatted data.

2. The apparatus as defined in claim 1, wherein the processing circuitry comprises a plurality of processing stages which are applied to the plurality of digital data streams to extract the formatted data.

3. The apparatus as defined in claim 2, wherein the processing stages include a demodulation stage, a decoding stage, and an error correction stage.

4. The apparatus as defined in claim 3, wherein the processing circuitry includes a buffer, in which data may be temporarily stored.

5.   The apparatus as defined in claim 4, wherein the demodulation stage, decoding stage, and error correction stage are all part of the concurrent portion of the processing circuitry, the buffer is part of the serial portion of the processing circuitry, and the multiplexer is disposed between the error processing stage and the buffer.

6.   The apparatus as defined in claim 4, wherein the demodulation stage is part of the concurrent portion of the processing circuitry, and the decoding stage, error correction stage, and buffer are part of the serial portion of the processing circuitry.

7.   The apparatus as defined in claim 6, wherein the multiplexer is interposed between the demodulation stage, and the buffer.

8.   The apparatus as defined in claim 6, wherein the multiplexer is interposed between the demodulation stage and the decoding stage.

9.   The apparatus as defined in claim 4, wherein the demodulation stage and decoding stage are part of the concurrent portion of the processing circuitry, and the error correction stage and buffer are part of the serial portion of the processing circuitry.

10.   The apparatus as defined in claim 9, wherein the multiplexer is interposed between the decoding stage and the buffer.

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11.   The apparatus as defined in claim 9,
wherein the multiplexer is interposed between the
decoding stage and the error correction stage.

12.   The apparatus as defined in claim 1,
wherein the sampling circuitry comprises a clock
recovery circuit for each of the data signals.

13.   The apparatus as defined in claim 12,
wherein each clock recovery circuit comprises phase-
locked loop circuitry.

14.   The apparatus as defined in claim 1,
wherein the sampling circuitry comprises synchronizing
circuitry for permitting a single clock recovery
circuit to be used to sample the plurality of data
signals, the synchronizing circuitry correcting for
variations in the linear velocities of the plurality of
data tracks.

15.   The apparatus as defined in claim 3,
wherein the demodulation stage comprises circuitry
implementing any one of eight-to-fourteen demodulation,
eight-to-fifteen demodulation, or eight-to sixteen
demodulation.

16.   The apparatus as defined in claim 3,
wherein the decoding stage comprises circuitry
implementing a cross-interleaved Reed-Solomon decoder.

17.   A method for processing a plurality of
data signals simultaneously read from a plurality of
data tracks of an optical disk to extract formatted
data, the method comprising the steps of:

sampling the plurality of data signals to
produce a plurality of digital data streams;

concurrently processing the plurality of
digital data streams;

multiplexing the plurality of digital data
streams into a single serial data stream; and

processing the serial data stream to produce
the formatted data.

18.   The method of claim 17, wherein the step
of concurrently processing the plurality of digital
data streams further comprises the steps of:

concurrently demodulating the plurality of
digital data streams;

concurrently decoding the plurality of
digital data streams; and

concurrently error correcting the plurality
of digital data streams.

19.   The method of claim 18, wherein the step
of multiplexing the plurality of digital data streams
follows the step of concurrently error correcting the
plurality of digital data streams.

20.   The method of claim 17, wherein the step
of concurrently processing the plurality of digital
data streams further comprises the step of concurrently
demodulating the plurality of digital data streams, and
the step of processing the serial data stream further
comprises the steps of:

decoding the serial data stream; and
error correcting the serial data stream.

21. The method of claim 20, wherein the step of multiplexing the plurality of digital data streams follows the step of concurrently demodulating the plurality of digital data streams.

22. The method of claim 17, wherein the step of concurrently processing the plurality of digital data streams further comprises the steps of:

concurrently demodulating the plurality of digital data streams; and

concurrently decoding the plurality of digital data streams; and

the step of processing the serial data stream further comprises the step of error correcting the serial data stream.

23. The method of claim 22, wherein the step of multiplexing the plurality of digital data streams follows the step of concurrently decoding the plurality of digital data streams.

24. The method of claim 17, wherein the step of sampling the plurality of data signals further comprises the step of generating a separate clock signal for each one of the plurality of data signals.

25. The method of claim 17, wherein the step of sampling the plurality of data signals further comprises the step of correcting a single clock signal to account for differences in plurality of data signals caused by variations in the linear velocity of the plurality of data tracks.

26. Apparatus for concurrently processing a plurality of streams of data simultaneously read from a plurality of tracks of an optical disk, the apparatus comprising:

a plurality of data stream processing circuits, each data stream processing circuit processing one of the plurality of data streams; and

a multiplexer for combining the outputs of the plurality of data stream processing circuits into a single data stream.

27. Apparatus as defined in claim 26, wherein each one of the plurality of data stream processing circuits comprises circuitry for demodulating a data stream.

28. Apparatus as defined in claim 27, wherein each one of the plurality of data stream processing circuits comprises circuitry for decoding a data stream.

29. Apparatus as defined in claim 28, wherein each one of the plurality of data stream processing circuits comprises circuitry for error correcting a data stream.
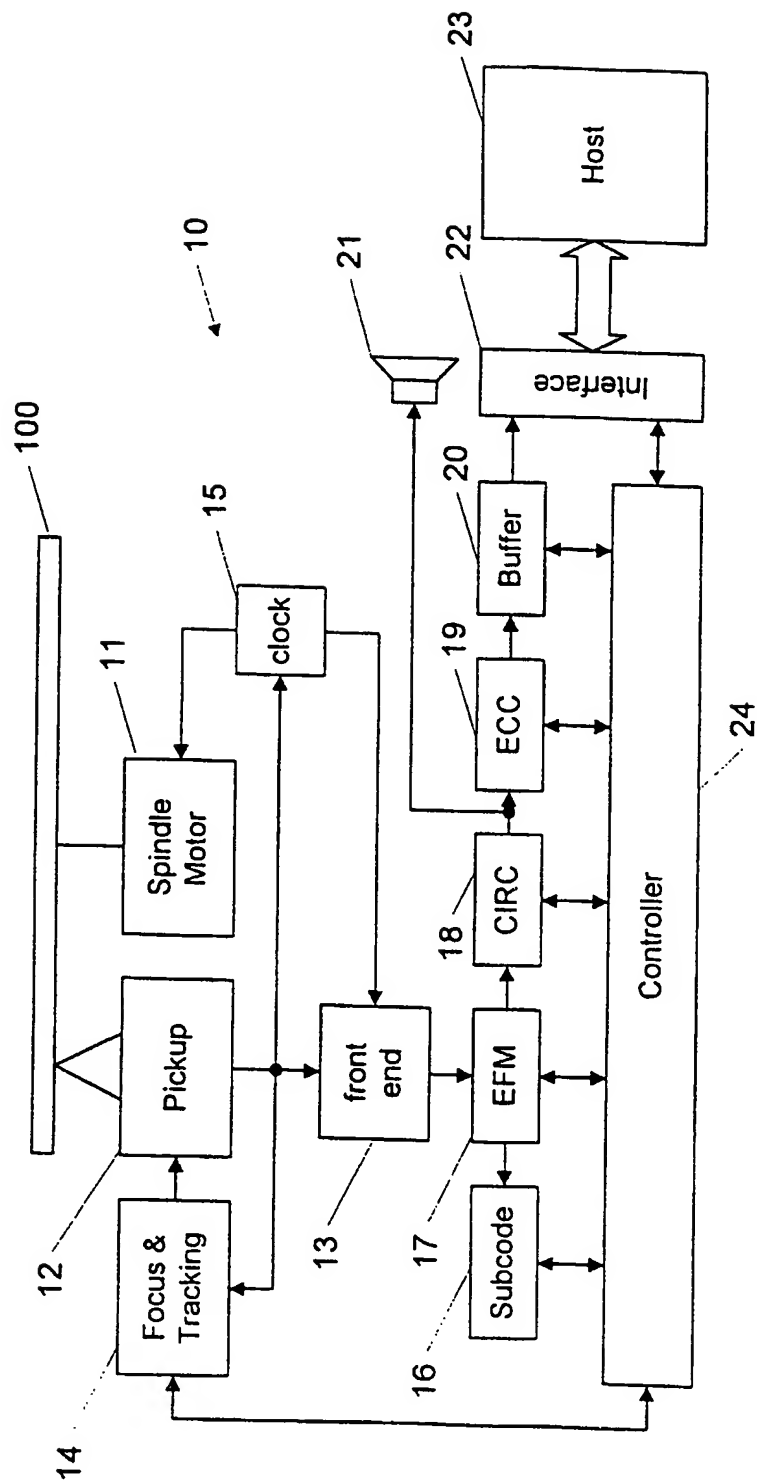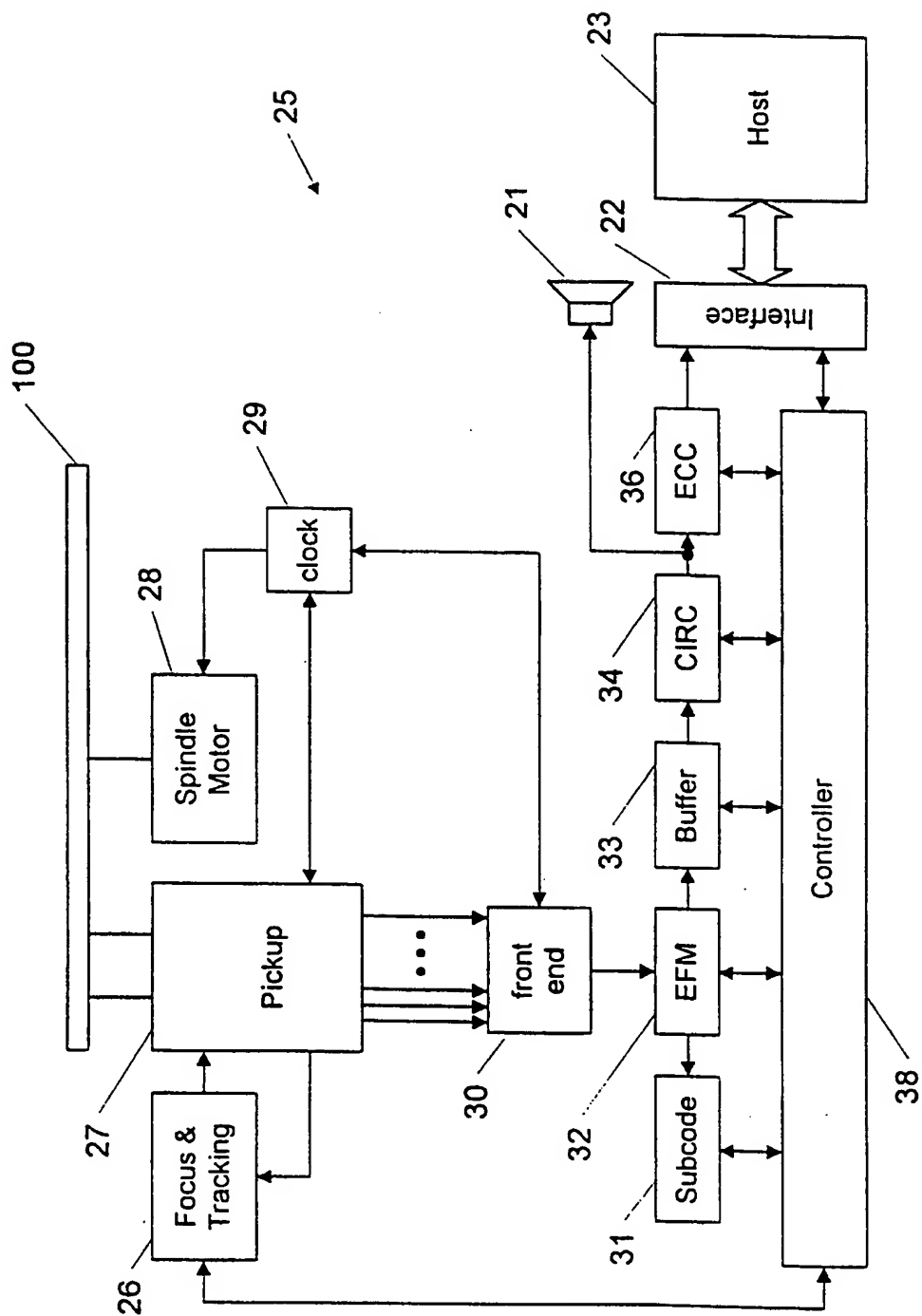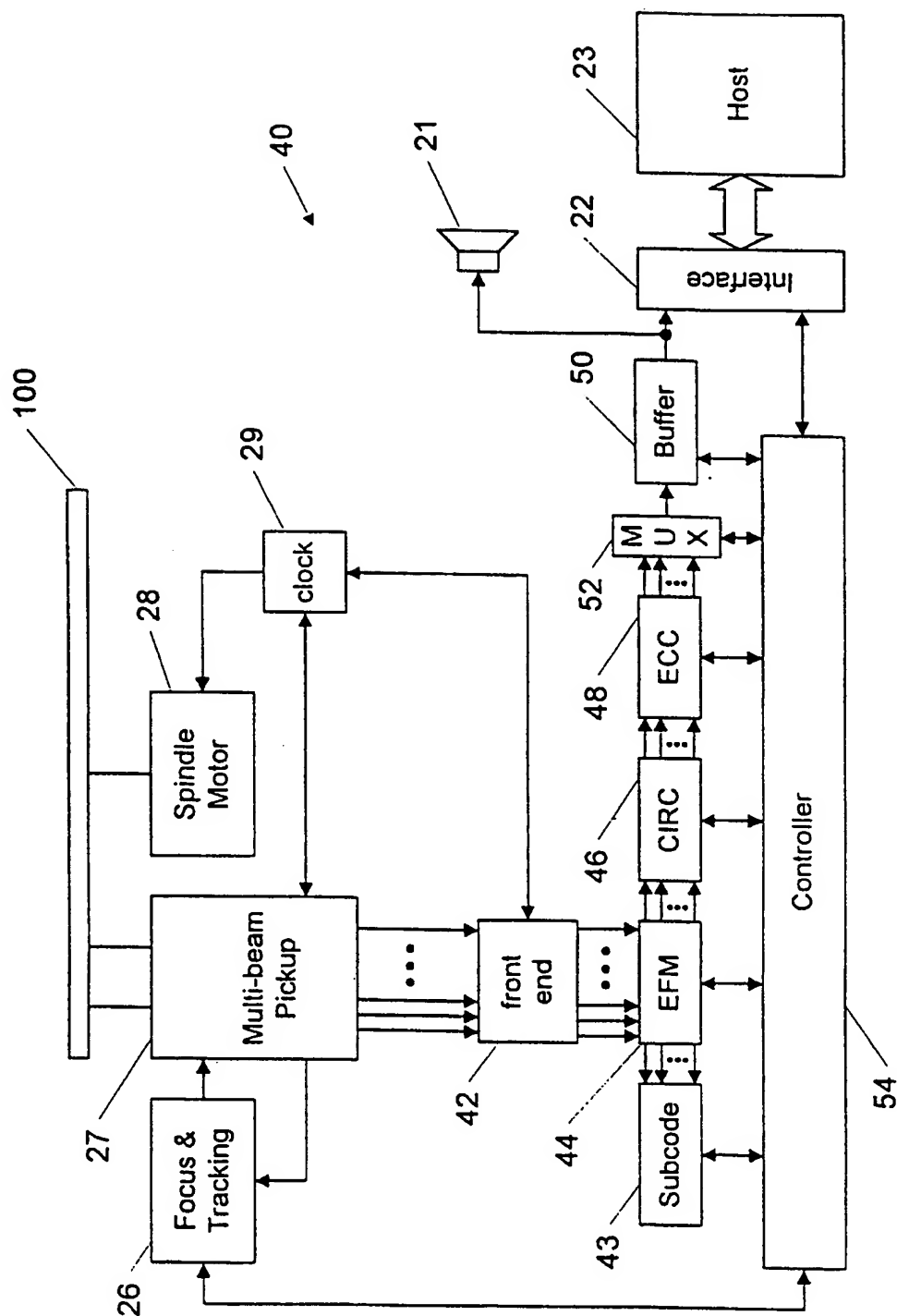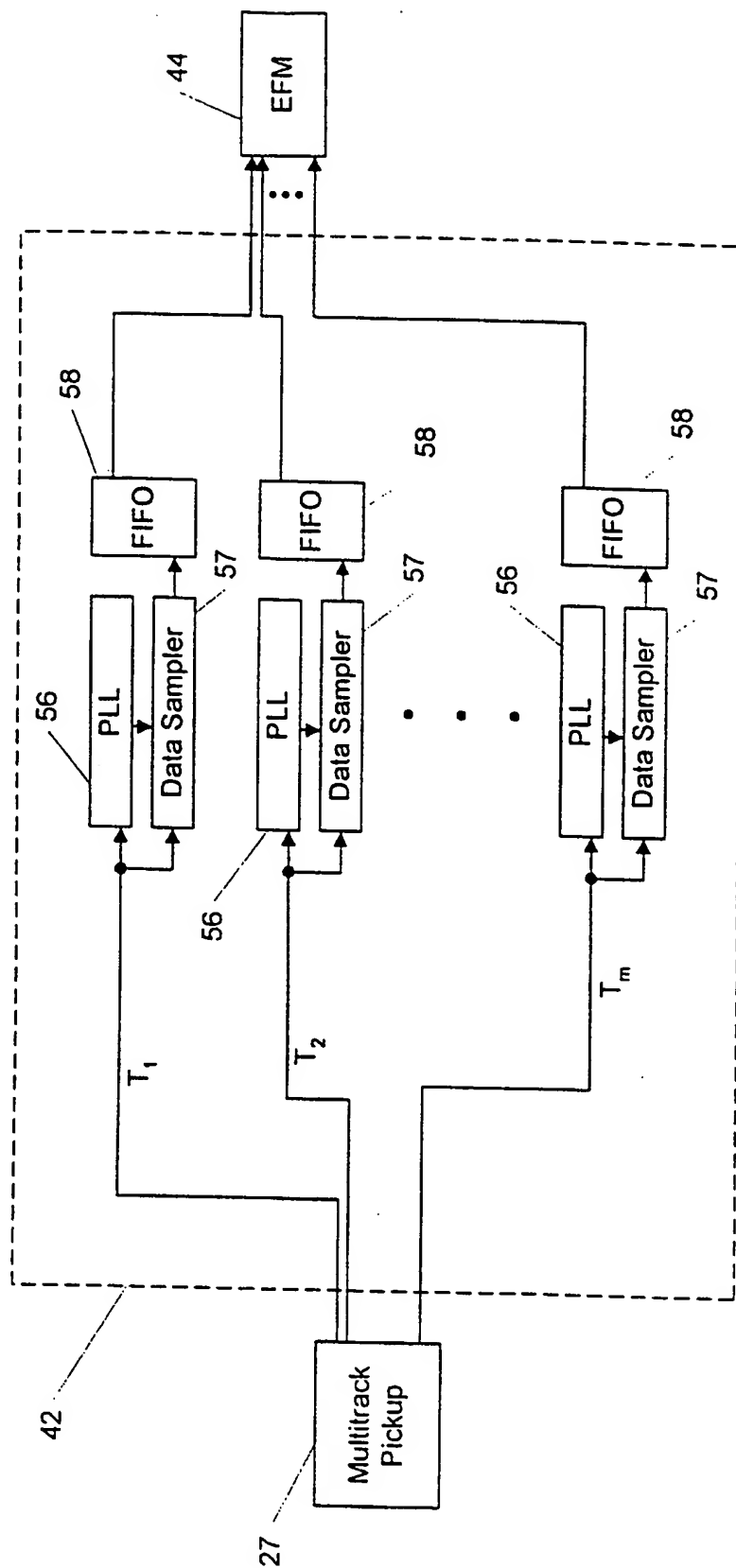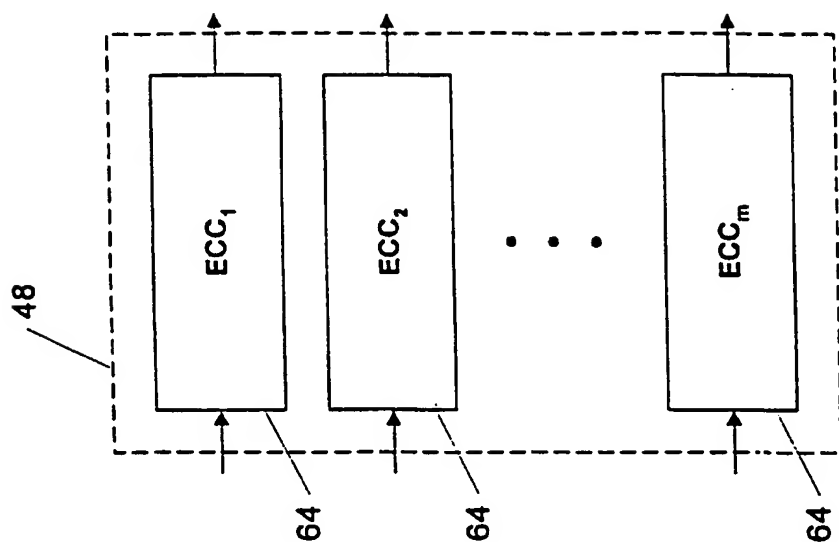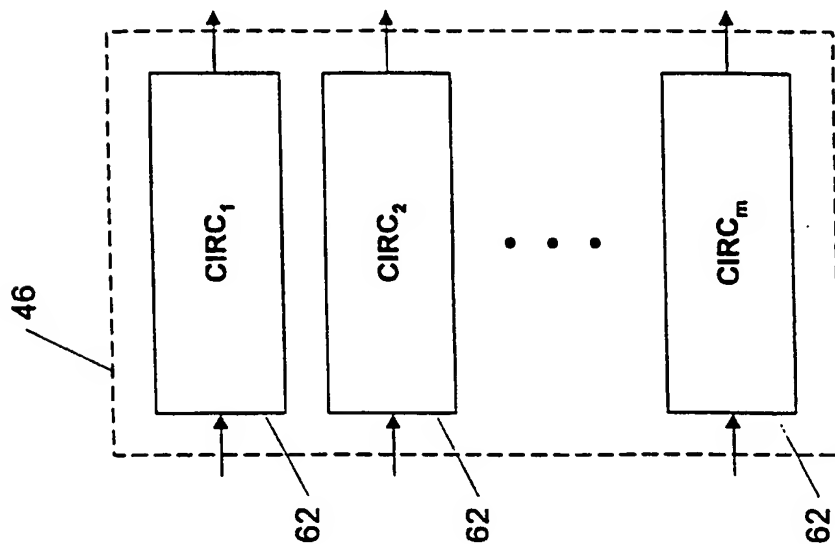
FIG. 1 (Prior Art)

FIG. 2

FIG. 3

FIG. 4

FIG. 5C

FIG. 5B
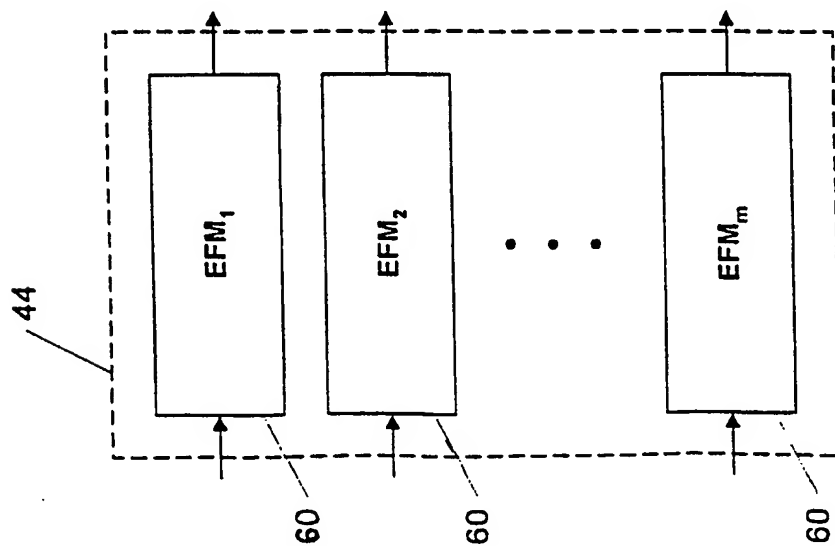
FIG. 5A
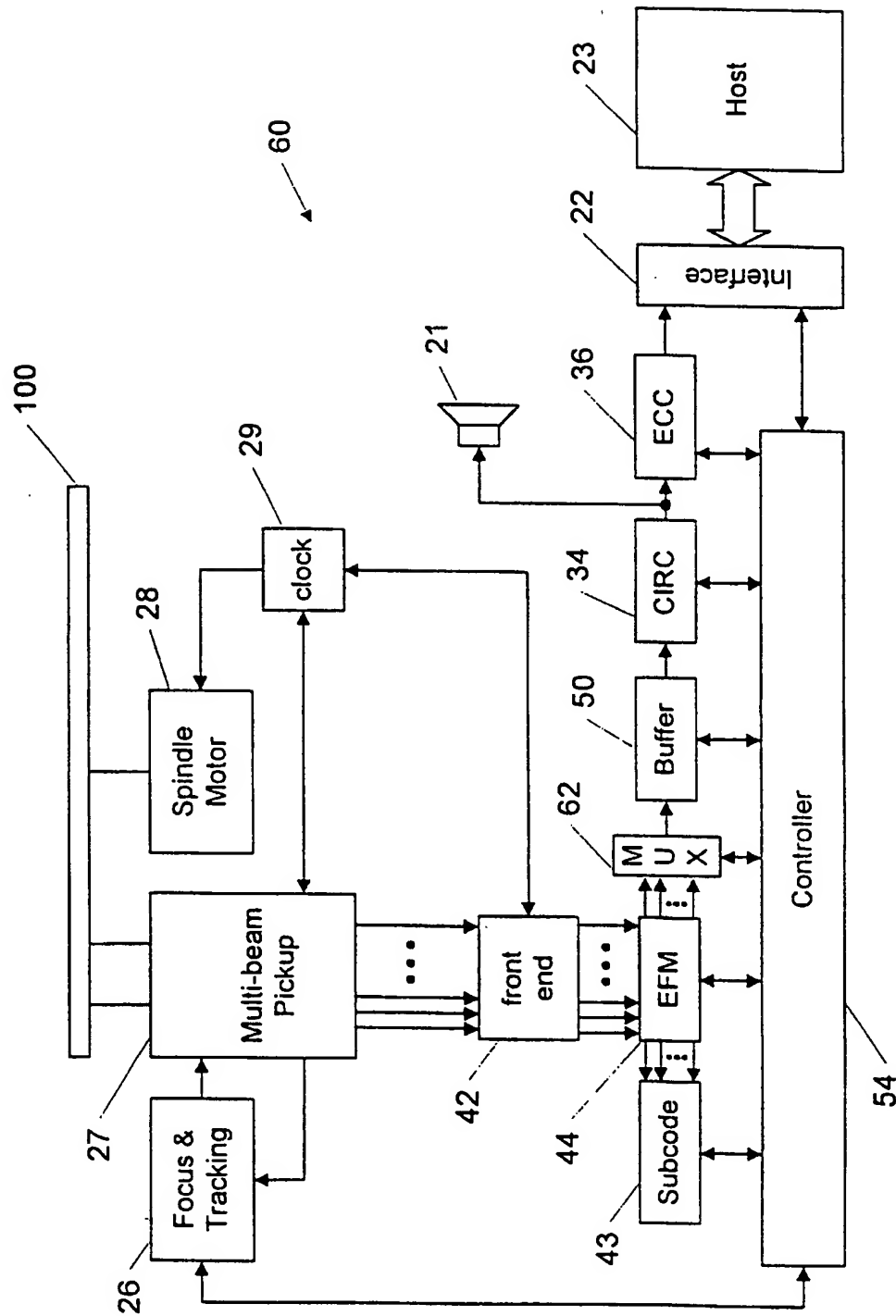
FIG. 6
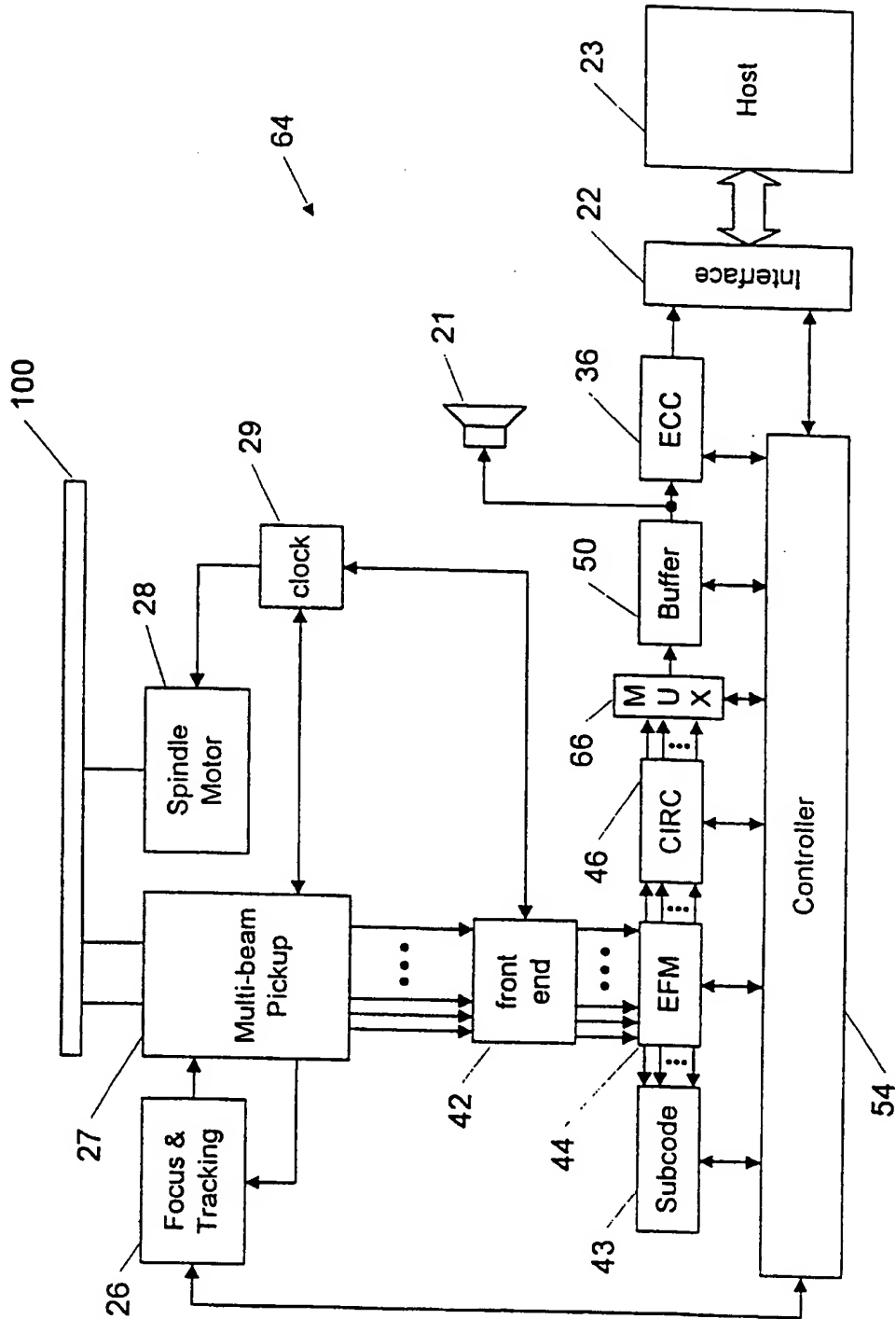
FIG. 7
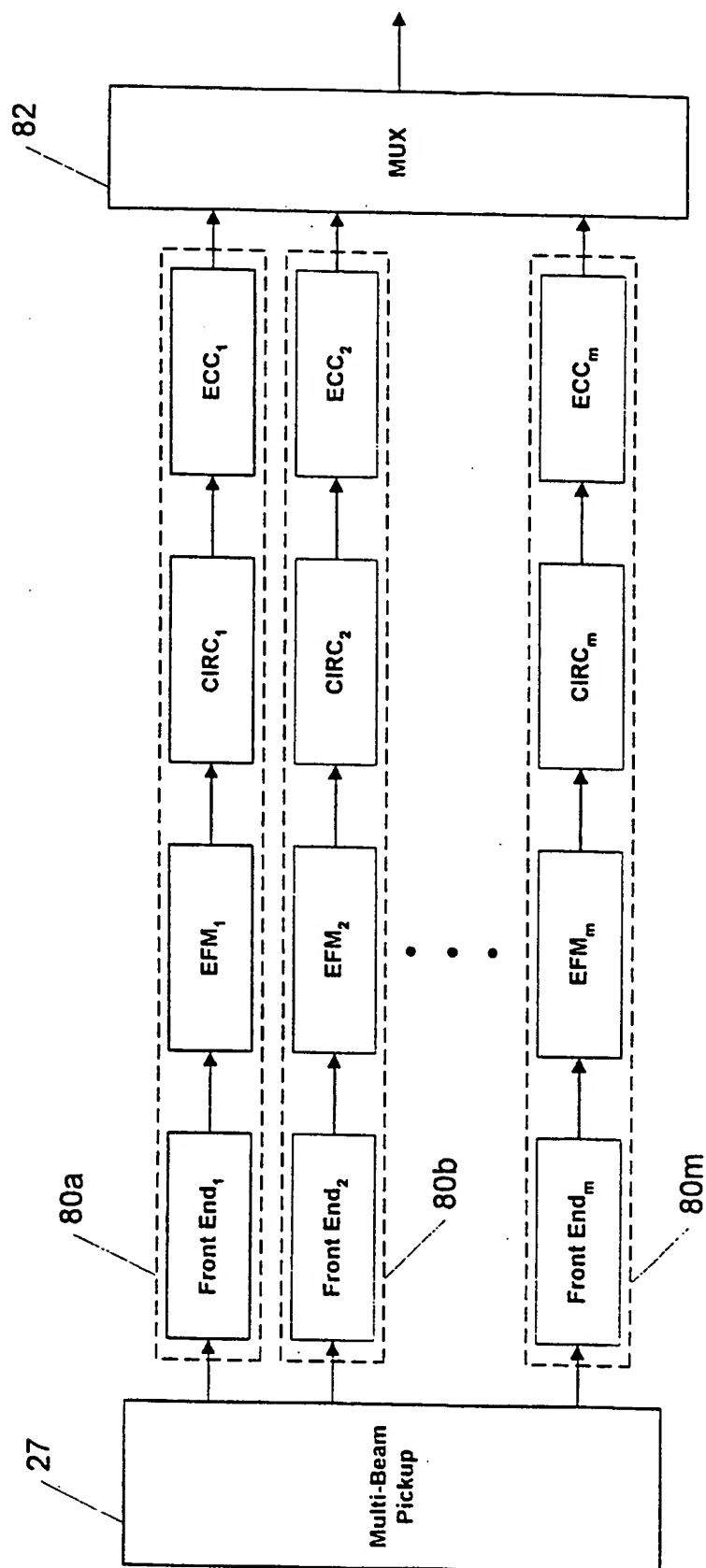
FIG. 8

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6   G11B7/14   G11B20/10

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6   G11B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 643 388 A (MATSUSHITA ELECTRIC IND CO LTD) 15 March 1995	1-4,6-8, 12,13, 17,20, 21,24, 26-29
	see column 14, line 15 - column 15, line 52	
	see column 19, line 56 - column 20, line 52; figures 6,14,15	
Y		14,16,25
A		5,9-11, 18,19, 22,23

Y	US 5 347 506 A (MATSUDO YASUNORI ET AL) 13 September 1994	14,25
	see abstract; figures 1,2	
A		15

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☒	Further documents are listed in the continuation of box C.	☒	Patent family members are listed in annex.

* Special categories of cited documents :

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 July 1998	17/07/1998

Name and mailing address of the ISA	Authorized officer
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	Inte Ional Application No
	PCT/EP 98/00984

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category ·	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
Y	EP 0 714 096 A (SONY CORP) 29 May 1996 see abstract see column 3, line 18 - column 4, line 42; figures 1,2 ---	16
X	EP 0 712 119 A (MATSUSHITA ELECTRIC IND CO LTD) 15 May 1996 see page 6, line 42 - page 7, line 5 see page 12, line 34 - line 55; figures 2,14	1,2,17, 26,27
A	---	3,15,18
X	EP 0 273 384 A (MATSUSHITA ELECTRIC IND CO LTD) 6 July 1988 see figure 7 -----	1,2,12, 13,17, 24,26

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